



United Kingdom
Hydrographic Office

“The Future of Celestial Navigation: A British Viewpoint”

Navigation and Timing 1730-2030: From Greenwich to Space
British Embassy, Washington D.C. 18-19 April 2013

Dr. Steve Bell – Head, HM Nautical Almanac Office, UKHO



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Navigation – The Present

■ GPS

- Source of shipboard system time
- Primary navigation input to WECDIS / ECDIS systems

■ Other navigation sources include:

- INS
- LORAN-C / eLORAN
- Ship's Compass / Log / DR / EP
- Radar
- Celestial Navigation





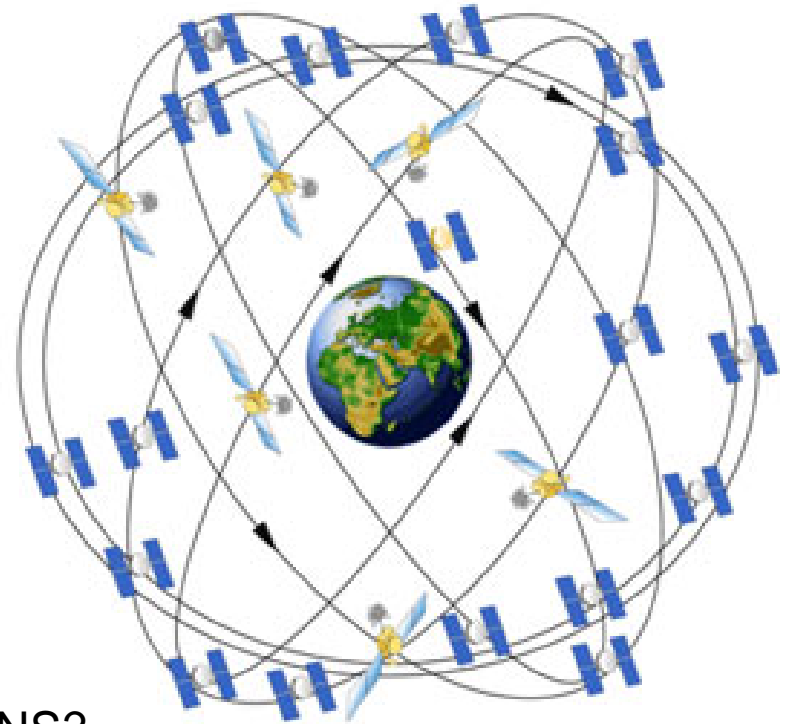
GNSS Systems

■ GPS/Navstar

- Currently 24+ Satellites
- Operational since 1994
- Position and time if you can see 4 or more satellites

■ Other systems

- Glonass (2007)
- Compass / Beidou 2 (2012-2020)
- Galileo (2014-2019)
- IRNSS (2012-2014) (regional) / GINS?
- QZSS Japan (2010-2013) (regional)





GNSS Weaknesses

- **Spoofing and jamming intentional or accidental – 1.5 watt transmitter can render GPS unavailable for 30km**
 - 2-year UK Sentinel project to determine scope of jamming
- **Damage to onboard antenna and ground stations, human error in providing updates to satellites**
- **Vulnerability of satellites to space weather considerations e.g. coronal mass ejections, high energy particles and radiation storms. Solar maximum ~ now (and every 11 years or so)**
- **Diffraction and refraction of signal in the ionosphere can generate position errors or at worst total loss of signal**
- **Shipboard time systems reliant on GPS**



GNSS Backups

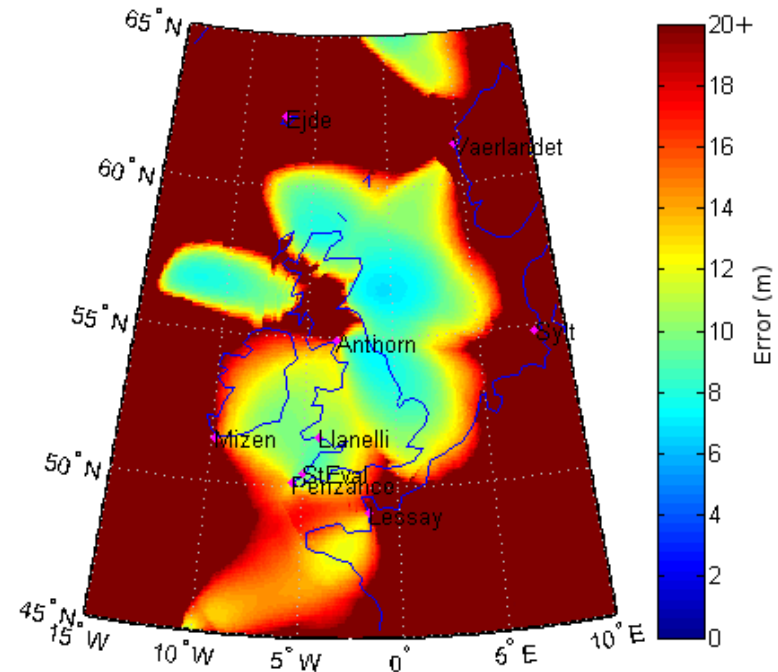
- **LORAN-C (absolute accuracy of 200-500 metres) (U.S., Canadian & Russian signals terminated during 2010)**
- **eLORAN (potentially good to +/- 8 metres) Full U.K. waters coverage by 2022**
- **Inertial Navigation Systems (integration drift of 0.6nm / hour)**
- **Celestial Navigation (good practitioners can reach <1nm)**
- **Contours of the seabed (not unique)**
- **Dead reckoning**



Backups – GPS+eLORAN

■ ACCSEAS (Accessibility for Shipping, Efficiency Advantages and Sustainability)

- Successful trials in the North Sea during March 2013
- Uses eLORAN
- Automatic immediate backup to GPS failure or loss of signal



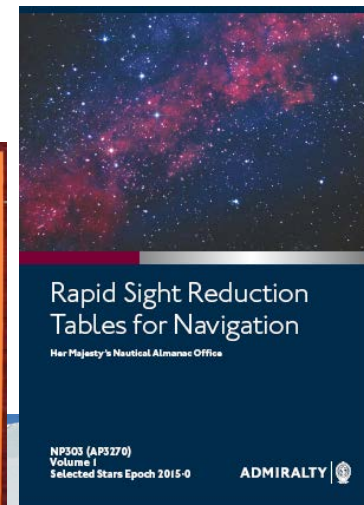
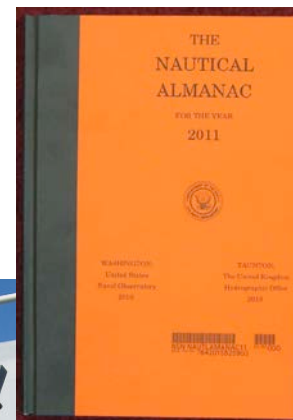
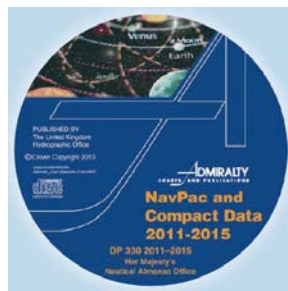


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Celestial Navigation

■ Celestial Navigation as a backup

- Nautical Almanac (USNAO /HMNAO)
- Sight Reduction Tables (USNAO/HMNAO)
- NavPac - HMNAO
- STELLA – USNO/AA
- UKAA – Royal Navy



■ Other commercial tools are also available



Strengths and Weaknesses of Celestial Navigation

■ Strengths

- Immune to jamming and spoofing
- Not controlled by a military or political organisation
- “Good for the Soul” (Prof. John Kemp, ex-RIN editor)
 - Personal discipline requiring minimal technology

■ Weaknesses

- Intermittently available – weather
- Moderate accuracy – ~1 arcminute or ~1 mile
- Training required to use it efficiently
- Dropping of leap seconds



Dropping Leap Seconds

■ International Telecommunications Union

- 2012 – Decision of drop leap seconds postponed
- 2015 – Vote planned for dropping of leap seconds

■ What it means if we drop leap seconds

- Link between UT1 and UTC broken ($UT1 \not\approx UTC$)
- Link between Earth rotation and Civilian time broken

■ What dropping leap seconds will mean for Navigators

- Knowledge of differences between UT1 and UTC
- UT1 almanacs replaced by UTC almanacs?
- More frequent almanac data to maintain accuracy?



102 years and counting ...

■ Collaboration between USNO & HMNAO

- Joint publications e.g.
 - The Nautical Almanac (NP 314)
 - Rapid Sight Reduction Tables (AP3270 / Pub. 249 / NP 303)

■ Benefits of the collaboration

- Shared expertise and complementary skills – security
- Avoidance of duplication of effort – efficiency
- Shared validation and checking of products – reliability

■ The Almanac Offices are the authoritative source of Astronomical & Celestial Navigation information



Feedback

■ Areas of Strength

- *The Nautical Almanac* is the pre-eminent source of almanac material either via direct sales or by licensing of copy
- It has the backing of two of the world's major almanac offices
- High profile users – you!

■ Areas of Weakness

- How is our material being used?
- Lack of feedback from our customers
- How do we start to address that communications gap?



“Astro-Navigation Solutions for the Future”

■ Meeting held on May 2nd 2012 in London addressing the following:

- Vulnerability of GNSS
- Independent backups to GNSS
- Use of The Nautical Almanac – is it too complicated?
- Software tools for Celestial Navigation
- Status of teaching of Celestial Navigation
- Incentive to learn Celestial Navigation techniques
- Future of Celestial Navigation as an independent backup



Participants

- **All four Royal Navy Fleet Navigators**
- **Lecturers from Teaching Colleges across the UK / HMS Collingwood**
- **International Federation of Shipmasters' Associations**
- **UK Chamber of Shipping**
- **Royal institution of Navigation**
- **Royal Yachting Association**
- **HNMAO / USNO / UKHO staff**



Speakers

- **Alan Peacock (Royal Navy retired – Fleet Staff Authors Group & former Editor of RIN Journal)**
 - “GNSS Denial and Astro-Navigation”
- **Roy Malkin (Maritime Warfare School / HMS Collingwood)**
 - “Overview of Astro Methods”
- **Catherine Hohenkerk (HMNAO)**
 - “Our current Astro-Navigation Solutions”
- **Material available @ <http://astro.ukho.gov.uk/nao/ansf/>**



Issues

■ **GNSS vulnerable to**

- Intentional or accidental jamming
- Inability to receive signals on board, damage to antennae, loss of power etc.
- Non-terrestrial influences e.g. coronal mass ejections, radiation storms, high energy particles etc.
- Signal propagation in a disturbed atmosphere
- Becoming a political bargaining tool

■ **No E-Loran due to funding issues**

■ **Loss of timing signals via GNSS**



Issues – II

■ Training

- Lack of properly trained crew, particularly in the Merchant Navy, to carry out celestial navigation
- Often no sextant on board
- No time or incentive to practice celestial navigation or to hone skills at sea

■ Lack of exposure of NavPac despite being the Royal Navy's chosen method of sight reduction.



Outcomes – I

- **GNSS denial is a real problem, significantly underestimated in the Merchant Marine sector.**
- **Unanimous agreement that celestial navigation was the main independent backup to GNSS**
- ***The Nautical Almanac* should be kept relevant and not “dumbed down”**
- **Better / more consistent celestial navigation training required in the colleges and at sea**



Outcomes – II

- **Star identification is a skill that needs to be improved**
- **Formal qualification of Celestial Navigation Specialist should be created**
- **Development and implementation at sea of automated celestial navigation in the longer term**
- **Increased use of new technology (mobile devices / apps) to make training of celestial navigation more attractive**



What this means for Almanac Producers

■ ***The Nautical Almanac***

- Possible move from a UT1 to UTC based almanac (ITU – 2015)?
- Improved star maps / star identification tools
- Polar latitude planning material to be moved from UK Air Almanac (U.S. Air Almanac) to *The Nautical Almanac*

■ ***Development of an enhanced NavPac***

- *E.g. addition of a specific Sun-run-Sun option*

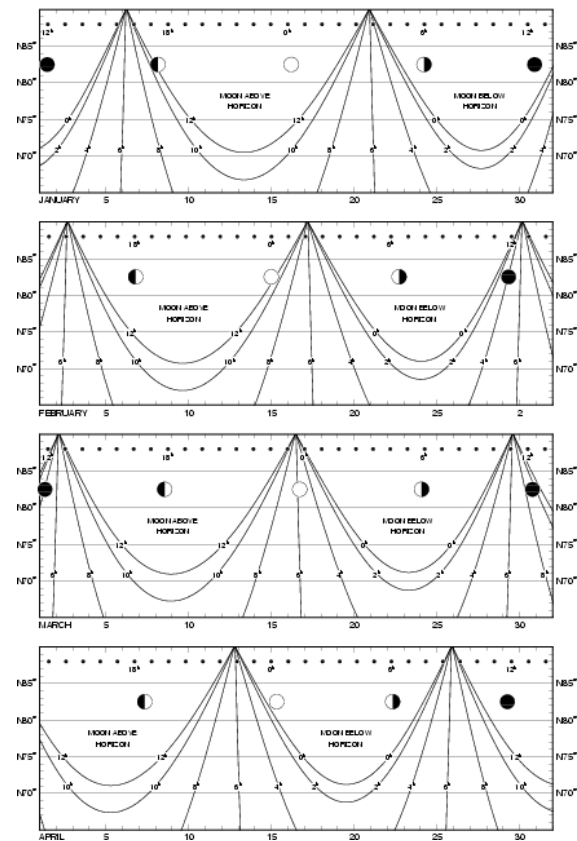
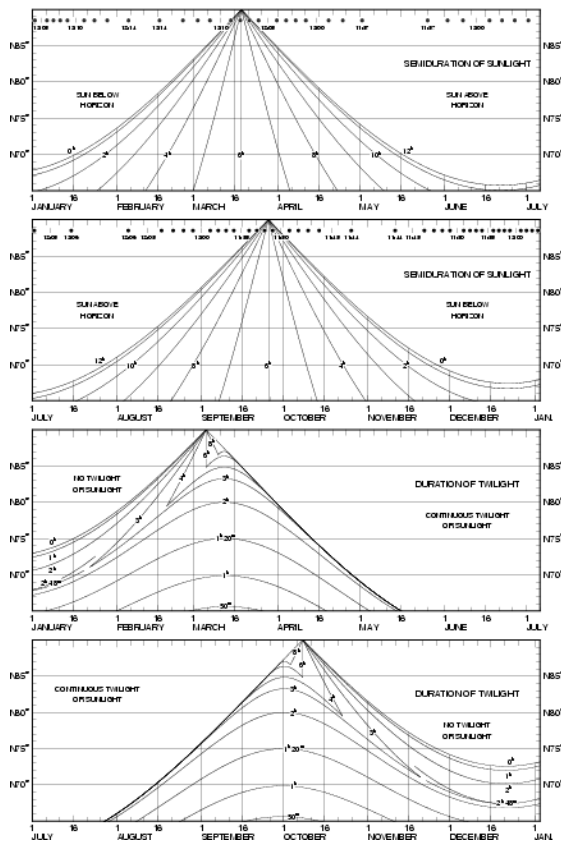
■ ***New modular publication / CD***

- *Workbook of celestial navigation examples*
- *Comprehensive star identification material*
- *Accessible appropriate Celestial Navigation teaching materials*



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Polar material (UK Air Almanac)

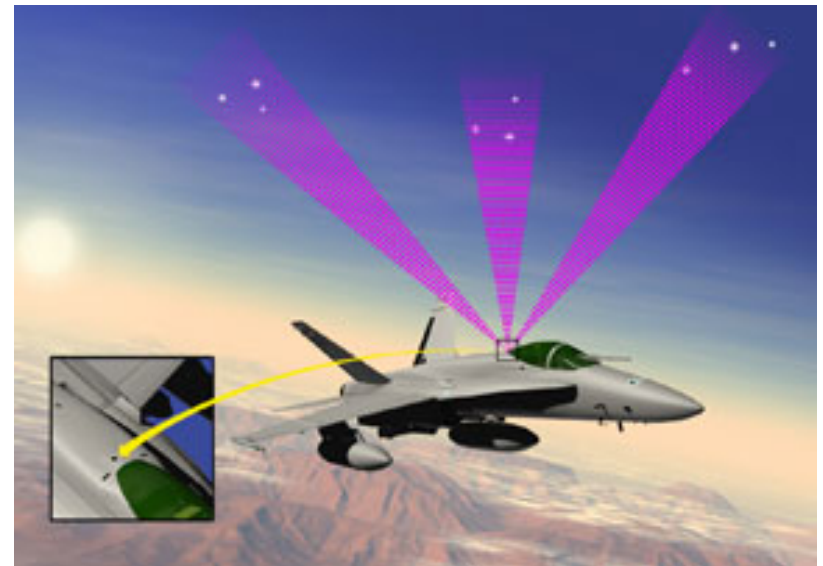




Navigation – The Future

■ Automated Celestial Navigation

- Multi-aperture device
- Star Pattern recognition
- Accurate star catalogues
- Capable of seeing naked-eye stars in daylight
- Operation in sub-optimal conditions



Source: TreX Enterprises



Timing – The Future

■ Chip Scale atomic clocks

- Smaller than a matchbox
- Uses 150mW of power
- Weighs tens of grams
- Accurate to about $0.5\mu\text{s}/\text{day}$
- Capable of installation in handheld GPS
- Available in mobile phones in a few years?



Source: Symmetricom

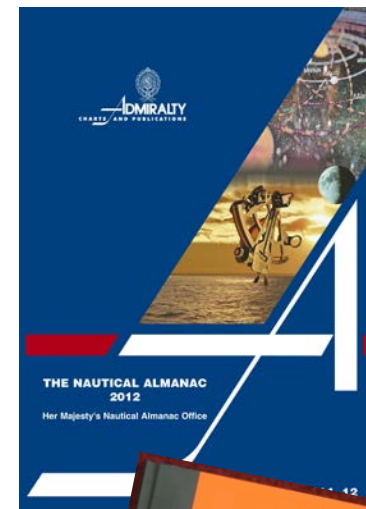
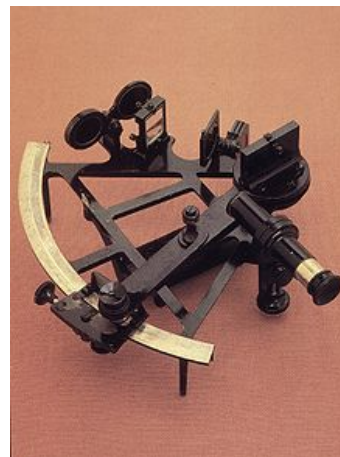


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The Independent Backup

- **In an emergency**
 - Carry a Sextant
 - Carry a Nautical Almanac
 - Know the time – UT1
- **Remember ...**

**The Nautical Almanac –
you can't jam it
and it doesn't crash!**





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Thank You!

■ **Any Questions?**